Relationship between Crater Shape and Its Projectile Point of Origin

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Abstract

This experimental study is to explore the relationship of the impact crater's shape and its projectile. In order to get a better estimation of the craters parameters, only the most clearly defined and typical crater patterns are chosen. An experiment was conducted at STRIDE (Science Technology Research Institute for Defense) to prove the relationship between impact craters shape and its projectile point of origin. One marble ball, a catapult and a basin of loose sands were used in the experiment. The motion of the marble was recorded using high speed camera with 1500 frame/second specification and the angle was estimated using frame by frame displacement measurement. The correlation between the impact angle, velocity and the depth of crater was investigated.

Keywords

Projectile Motion; Crater Analyses; Impact Crater Shape; Projectile Point of Origin; Crater Depth; Ellipticity; Loose Sands Experiment

Introduction

According to P.H Schultz et al., the final diameter and depth for simple (un-collapsed) craters are commonly assumed to form a constant ratio meaning that the crater diameter and depth are proportional. If the crater diameter is referenced to the pre-impact surface, it is termed the apparent crater and the aspect ratio ranges from 3:1 for the strength-controlled crater-scaling regime to 4:1 for gravity-controlled crater-scaling regime [P.H. Schultz et al., 2005].

In order to validate the relationship between the impact angle, crater shape and crater depth, an experiment was carried out at STRIDE area using catapult and marbles having impacted on loose sand to analyze the impact crater shape and its parameter. The collected data on crater measurement are used to verify the crater shape then the angle of impact was estimated using the projectile motion video taken by high speed camera. Besides, the relationship between the impact angle and the crater shape from the algorithm was analyzed and by the end of the experiment we can conclude that the results from the algorithm agreed with the experiment. The relations suggest that when a projectile launched from the impact angle 90 degrees or near, the resulted shape crater will be a circle instead of an ellipse. In other words, when the impact angles became smaller, the craters will be more elongated.

As a limitation, only loose sand is used as an impact medium to produce a fine crater's shape because the marble impact does not have as high velocity as the bomb to get a clear bowl-shaped. Moreover, the ranges of speed during marble's flight are only estimation as no accurate equipment has given an accurate speed. The experiment has considered an ideal environment only; which means no air drag is included to make the computation less complexity.

Methodology

The experiment was held using catapult, marbles, basin with a large amount of sands and high speed camera to record the marbles' motion and measure the impact craters.

The objective of this experiment is to determine the relationship between the angle of impact and the crater shape. The high speed camera was placed in front of the basin of sands with same height so that we got the right angle to ease the calculation of the angle from the grid.

Moreover, the high speed camera was put as far as possible from the basin while the basin was put as close as possible to a grid background to eliminate parallax error as much as possible. The motions of the

FIG. 1 EXPERIMENT SETUP

FIG. 2 LEFT: HIGH SPEED CAMERA, THE BASIN OF SANDS AND A GRID TO ESTIMATE THE ANGLE, RIGHT: HIGH SPEED CAMERA USE TO CAPTURE THE MOTION OF THE PROJECTILE.

marbles/projectiles were recorded by the high speed camera. The specifications of the high speed camera are:

- The frequency is set to 1500 frames per second.
- The shutter speed of the high speed camera was set to 1/2000seconds.

Semi major axis, semi minor axis, position of the deepest point and depth of the impact crater were measured. 60 samples were measured with four different forces and 5 different angles. Each forces and angles will have 3 samples. A square grid of 2 cm x 2 cm was used to ease the calculation of motion and placed behind the basin. The distance between the grid and basin was recorded as 28 cm while the distance between the basin and the high speed camera was recorded as 311 cm. This distance is important to scale back the calculation when we estimate the angle soon.

There were some assumptions made prior to the experiment:

- The experiment area is nearly wind-free (no air drags along the launch period), which we only consider the free air drag equation to determine the horizontal displacement, *R*.
- The ballistic motion of a catapult is actually a semi-circle projectile movement but we judge only half way of it and assume that the angle and velocity upon impact is almost uniform.

Experimental Procedures

One marble ball was launched from the catapult from four different forces namely *Force 1*, *Force 2*, *Force 3* and *Force 4* with the range of Force 1 to Force 4 representing increasing force. Force 1 represents the velocities ranging from 1600mm/second to 2900mm/second, *Force 2* represents the velocities ranging from 2200mm/second to 3100mm/second, *Force 3* represents the velocities ranging from 2700mm/second to 4200mm/second and *Force 4* represents the velocities ranges from 3400mm/second to 5400mm/second. Each projectile's motion was recorded by the high speed camera with 1500 frames/second specification. The catapult's angle of launch was estimated to four different angles: 30, 45, 60, 75 and 90 degrees with four different forces representing each angles. By looking at the grid line below, x is the measurement of displacement in x axis and y is the displacement in y axis.

As seen in FIG. 3, a basin filled with sands was prepared. The beach sand was used because the texture was more fine and easy to create a crater.

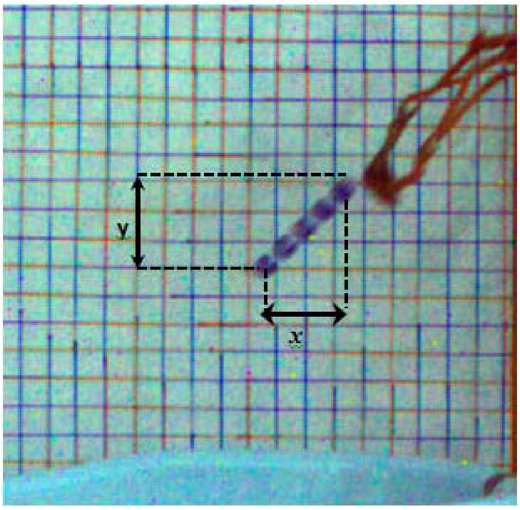


FIG. 3 IMPLEMENTED TECHNIQUES TO ESTIMATE THE IMPACT ANGLE

The catapult with marble were launched near the basin to make sure that the marble were landed on

sand. The position of the center of craters in those 60 samples was set to be as consistent as it can be to prevent the perspective distortion when estimating the angle of impact taken by the high speed camera. After the marble impacted the sand, the position of the deepest point (depth) in x and y direction, depth, semi major axis and semi minor axis were measured for each sample of crater. All the craters parameters were measured using a digital caliper.

The sand were flattened by the ruler each time after each sample were taken. For each force, there will be five different angles. For each angle there will be three trials conducted to quantify random errors. There will be 15 samples in every forces and 60 samples overall. Throughout the experiment, the same marble was used together with a similar type of sand. At first, the experiment were conducted in the laboratory room but there were no enough light to supply a high speed camera. To get a better video for projectile motion, we searched a place outside with a high wall to minimize the air drag that will distort our readings. The experiment was conducted in a nearly perfect weather with a minimum air drag. The results were reported in the experimental result section.

Experimental Results Formation of Elliptical Craters

The ellipse parameter of the impact crater such as semi major axis, semi minor axis, position of the deepest point and depth were measured during the test. The test was carried out in small space with almost free from wind and it were assumed that it were no air drag. 60 samples with various launching forces and angles were taken during the test. The test was held using a catapult, a marble and a bowl of sand. The dry loose sand was used as an impact area. The high speed camera was used to record the projectile's motion and the frequency was set to 1500 frames per second. The impact crater on the sand was measured to determine its semi major axis, semi minor axis, the position of the deepest point and depth. The size and the shape of the craters vary with the various forces from the catapult. When a ball is dropped into sand at almost 90 degrees or exactly 90 degrees, it is proved that a circular crater is formed rather than elongated craters. The ellipticity is almost 1 or 1 for 90 degrees. The ellipticity is defined as the quotient of its maximum (semi major axis) and minimum (semi minor axis) rim-to-rim diameters (Bottke et al., 2000). The results of crater ellipticity versus impact angle for different forces as a function of impact angle are summarized in FIG. 4 below.

Moreover, by referring the four graphs in FIG. 5, they are 60 samples taken to determine the relationships of maximum crater diameter and crater ellipticity. Every force has 15 samples each. The data points showed only 15 (25%) of them which formed a circle shape. The rest 45 craters or 75% samples are ellipses. Based

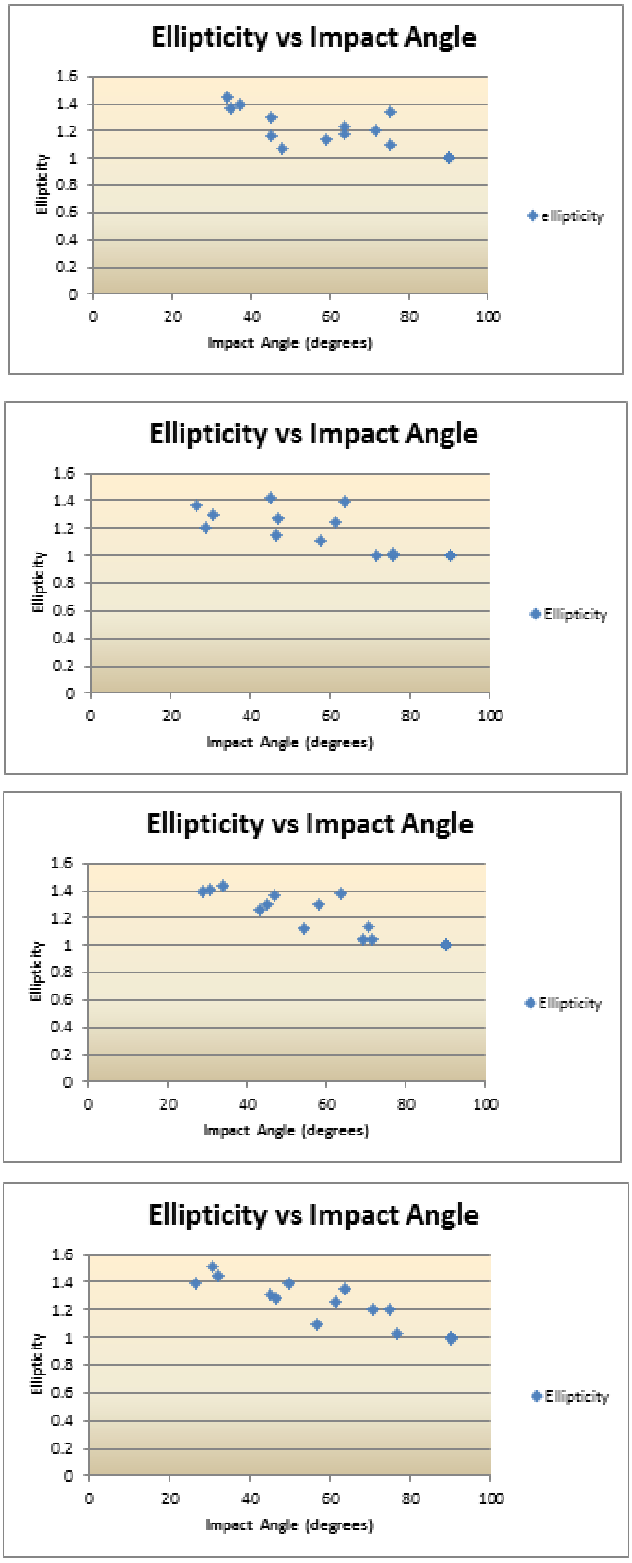


FIG. 4 ELLIPTICITY VERSUS IMPACT ANGLE (FORCE 1, FORCE 2, FORCE 3, FORCE 4)

on the previous explanations, the ellipticity is defined as the quotient of its maximum (semi major axis) and minimum (semi minor axis) rim-to-rim diameters. The ellipse is said to be more elongated if the ellipticity value is more than 1, while the ellipse will return circle if the ellipticity, ε=1 (Bottke et al., 2000). The crater maximum diameters have a range from 80 millimeters to 140 millimeters for *Force 1*until , *Force 4*.

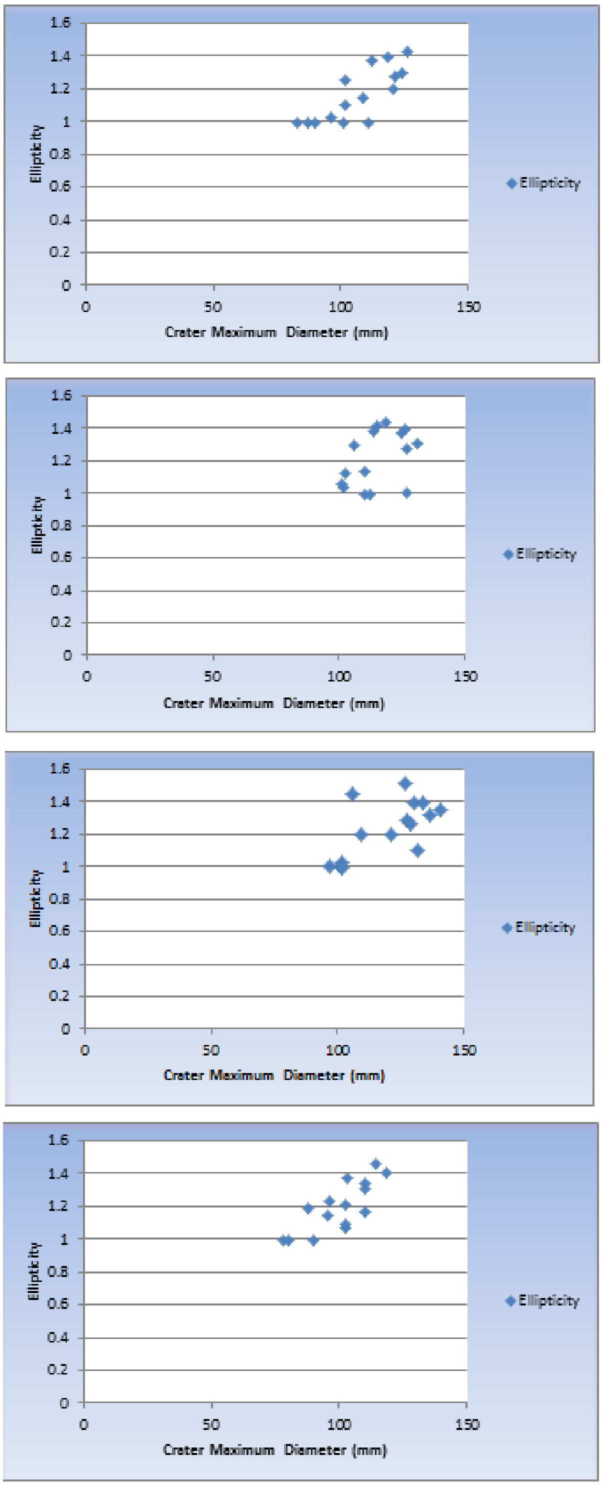
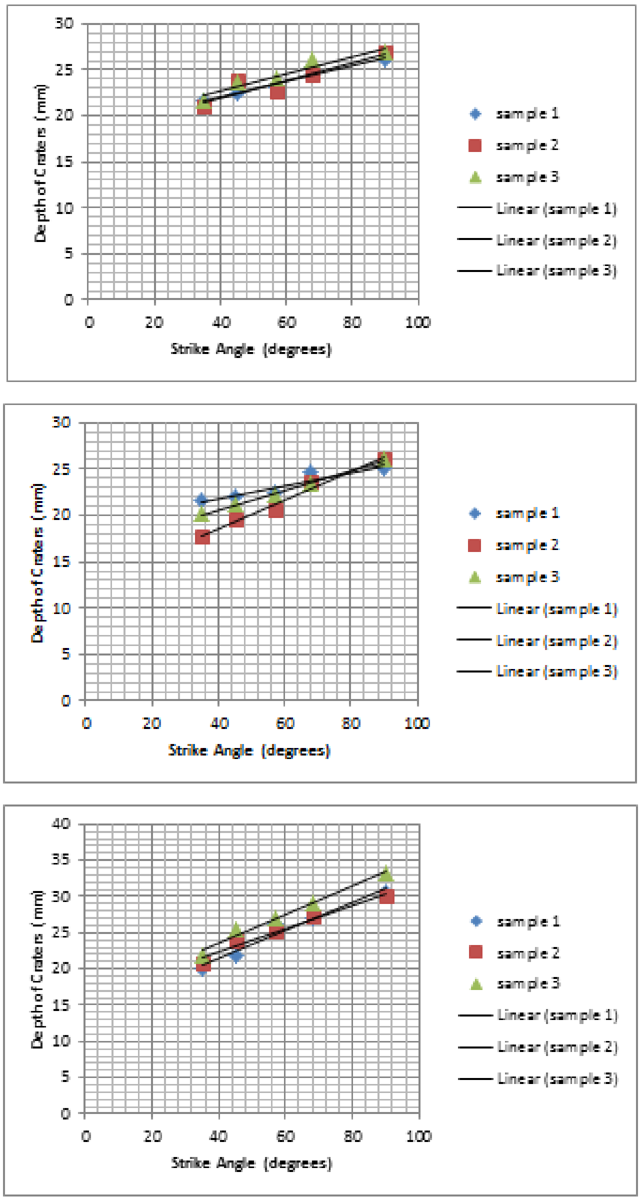


FIG. 5 ELLIPTICITY VERSUS CRATER MAXIMUM DIAMETER (FORCE 1, FORCE 2, FORCE 3, FORCE 4)

Analysis of the Crater Depth and Impact Angle

Moreover, the correlation between the crater depth and angle of impact is also investigated. The crater depth versus angle of impact graphs are observed for various forces as illustrated in FIG. 6. The pictures represent *Force 1* till *Force 4.* Sample 1 is the first trial of marble's launching, sample 2 is the second trial and sample 3 is the third trial. Therefore, every force has 15 samples of marble's launching.

From four different forces graphs, we can conclude that the patterns are the same. The strike angle and the crater depth are proportional to each other. Increasing strike angle will produce deeper crater depth and vice versa. Moreover, increasing in force also will give deeper crater depth.



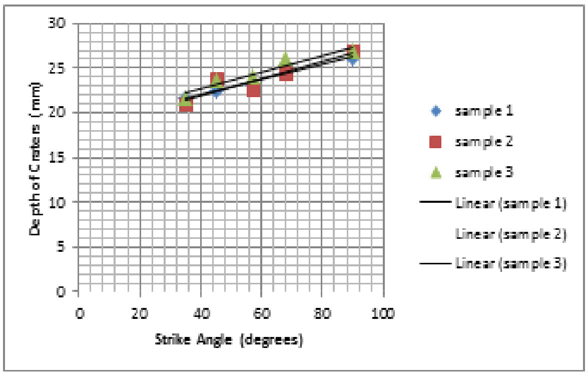
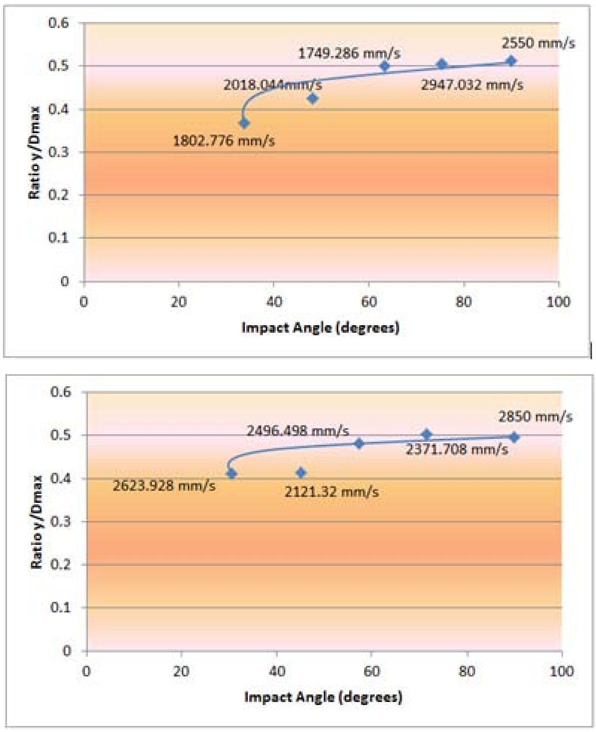


FIG. 6 RELATIONSHIP BETWEEN DEPTH OF CRATERS AND IMPACT ANGLES FOR FORCE 1 TILL FORCE 4

Analysis of Radius Y/Maximum Diameter (Point Position Ratio) Versus Impact Angle

The analysis of position of the deepest point, Y/Y_{max} (Point Position Ratio) versus impact angle is studied. By looking at the FIG. 7, the curve patterns are similar for four different forces.

The average velocities of each sample trial are given in the graph. The maximum value of the deepest point position ratio (Y/Y_{max}) is obviously 0.5 from the center of the crater. Therefore, whenever the impact angle became steeper, the ratio value will increase and at 90 degrees, the maximum value of 0.5 will appear since the deepest point has been at the very center of the crater. Since the deepest point (depth position in x and y direction) is a center of a circle, the crater radius will be half of the diameter, which is 0.5. If the deepest



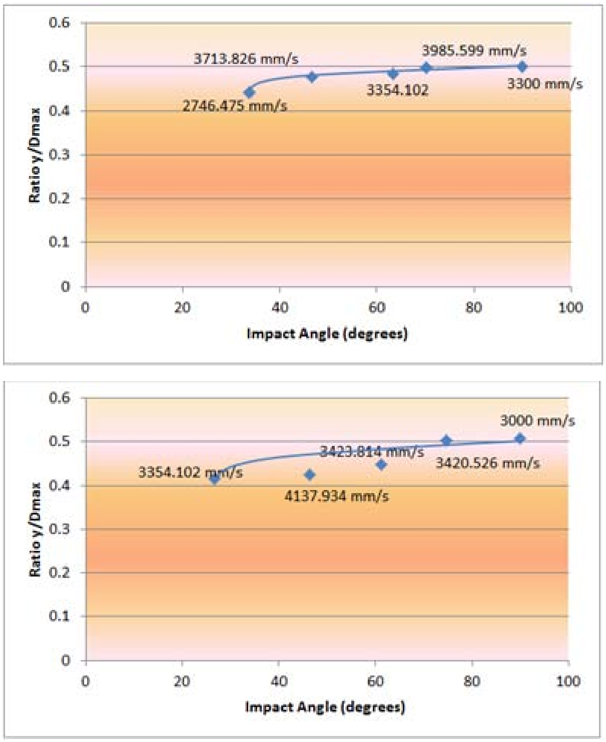


FIG. 7 RELATIONSHIP BETWEEN THE DEEPEST POINT POSITION RATIOS VERSUS IMPACT ANGLES FOR FOUR FORCES (FORCE 1 TILL FORCE 4)

point is less than 0.5 from the center of the crater, the crater will become more elongated and form an ellipse shape.

Conclusions

This research reported the relationship between the impact crater shape and its projectile point of origin. A small scale cratering experiment in loose sand was carried out to verify the relationship between the impact crater shape and its projectile point of origin. The hypothesis made prior to the experiment also matched with the results which revealed the successfulness of this project.

Craters are tends to be circular at steeper impact angles and become increasingly elongated at shallow impact angles. The experiment was done with some assumptions for easiness measurement and calculation. The results and hypotheses agreed with those conference and journal papers from other researchers as well (read: Bottke et al paper 2000). The results were 1) the ellipticity value tends to approach 1 as it comes to steeper angle and it formed a circle shape thus verifying that the crater detected in the algorithm has a projectile impact angle of 90 degrees or nearly that angle 2) the ellipticity value that is away from 1 is tend to form an ellipse, and it becomes more elongated at shallow impact angle 3) From the taken 60 samples,

the data points show only 15 (25%) of them which formed a circle shape, the rest 45 craters or 75% samples are ellipses 4) The impact angle is actually proportional to the crater depth 5) The correlation between the ratios of the deepest point position against diameter is observed and it has been observed that whenever the impact angle became steeper, the ratio value will increase and at 90 degrees, the maximum value of 0.5 will appear since the deepest point is at the very center of the crater. Since the deepest point (depth position in x and y direction) is a center of a circle, the crater radius will be half of the diameter, which is 0.5. If the deepest point is less than 0.5 from the center of the crater, the crater will become more elongated and formed an ellipse shape.

ACKNOWLEDGEMENT

This paper is fully supported by the Department of Electricaland Electronics, Universiti Pertahanan Nasional Malaysia.

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